Fast, Space Qualified 3000 V Modulator for a Cloud Profiling Radar

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Abstract

Cloudsat's Cloud Profiling Radar (CPR) delivers a 2 kW of RF pulse using an extended Interaction Klystron (EIK). 'To drive such an EIK, it was necessary to develop a -16.3 kV High Voltage Power Supply (HVPS) and a Focus Electrode Modulator (FEM), floating at Cathode potential to turn the EIK's Beam on and off -45V to -3kV with respect to the Cathode. This paper describes the design approach for the FEM and its performance at EM and Flight Configuration. In author's opinion it a simple but universal approach which allow designer to achieve greater flexibility and freedom in designing high swinging space qualifiable FEM.

Introduction

This paper described the development of a fast 3000 V Focus Electrode Modulator (FEM) to drive a 2 kW, pulsed Extended Interaction Klystron as part of a High Power Amplifier (HPA), see figure 1, used in the Cloudsat Profiling Radar (CPR) due to launch in June of 2005. This will be the first Radar instrument to fly in space at this power, operating voltage and high speed 3000V FEM (rise and fall time of less then 200 nanoseconds). The EIK was developed by Communication & Power Industries of Canada (CPI) and has been published (ref 1, 2)

The Modulator floats at a cathode potential of -16.3 kV and the modulator, when in cut-off, is -3.0 kV with respect to cathode. FEM output is at -45V with respect to Cathode when the beam-on state.

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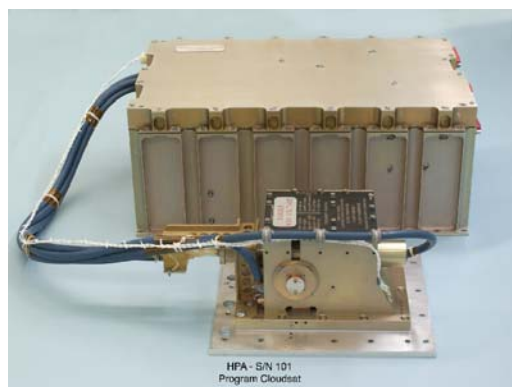

Figure1: Cloudsat High Power Amplifier

Therefore the challenge was the containment of extreme high voltage (-20 kV) and as well as high slew rate of modulator voltage and retain the rise and fall times without any special screening of any part

There are many ways of achieving the performance, but JPL selected a push-pull arrangement using four (4) appropriately de-rated high voltage FETs in series in each of the Push/pull stage (referred to as a four stage Modulator).

For the Flight units, the design had to be modified to a 10 stage configuration (10 each in each for pull and 10 each for the push stage) due to orbit-dictated radiation environment and tests of flight FETs. Both four stages and ten stages Modulator completed there environmental and thermal vacuum test and met all the performance requirements.

Basic Electrical Design

Figure 2 below shows a generic Block Diagram for the Focus Electrode Modulator (FEM). The A5 and A6 Block each contain four or ten series FETs.

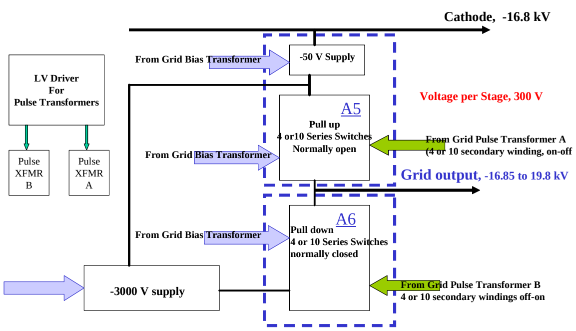

Figure 2: Generic Block Diagram (4 or 10 Stages)

Basic Top level Layout (not to scale) of the FEMs elements are shown in figure 3.

The A5 stages are designed such that in: absence of Pulse Command the output FETs are biased negative with respect to their sources. The A6 stages are biased on. Each stage (switch) has its own driver commanded driven by a four (4) or ten (10) secondary transformer.A5 Pulse transformer (A) is out of phase with A6 pulse transformer (B).

The pulse transformers are designed to minimize capacitance to primary winding and equalize capacitance between secondary windings and maximize coupling to the primary

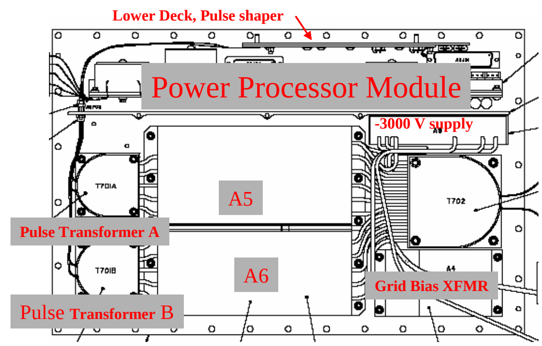

Figure 3: Basic FEM layout for Flight Units

. This approach insures that the driving pulses are within 5 nanoseconds of each other. With this approach each stage is actively driven on and off to insure the output stages are turned on and off and the voltage division between stages remains equal in transitions and in steady state. In off mode each FET has equalizing shunt resistors to account for the variation in leakage current over life and temperature. The above was, in part, verified by p-spice simulation. Data shown in Table 1 and figure 4 is for a four stage FEM and shows the rise and fall time are well within the limits of desired performance.

Table 1: EM Test data (4 Stage per FEM)

	Temperature, C		**-20**	**25**	**55**	**70**	Req.
	Grid On	Volts	-53	-34.83	-35.1	-35.4	
	Grid cutof	volts	-2839	-2845	-2807	-2809	
	Grid Dela	nano sec	500	525	552	544	
	Grid Rise	nano sec	170	147	178	180	200
	Grid Stota	nano sec	750	800	854	889	
	Grid Fall	nano sec	50	73	72	41	200

The delay is cased by the pulse shaper on the lower deck

Note: Breadboard and EM utilized a four (4) stage and Flight unit utilized a ten (10) stage design.

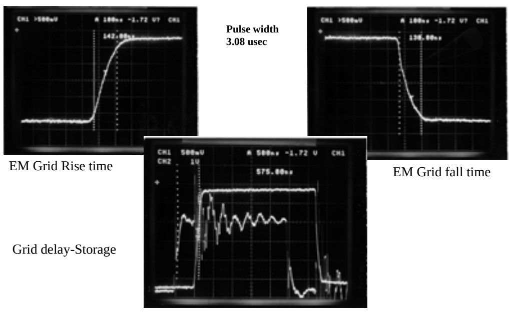

Figure 4: The Grid Rise, fall and delay

Containment of High voltage and high slew rate.

High voltage designer are fully cognizant of the dangers of high electric stress, presence of corona and temperature. In this design care was taken to insure that the assemblies were corona free at or above the operating voltages and electrical stress, corona and temperatures were consistent with the 12 year design life.

Figure 5 shows the flight configuration of the FEM. There are six cards for A5 and five cards for A6. The 6th in A5 card is dedicated to the Focus electrode ON voltage. Each of the cards in A5 and A6 contain two stages. Therefore the maximum potential between any two cards is less then 600 Vdc.

The uniqueness of the design is that the back side of the assembly is at a uniform potential, but are separated by 600 V (worst case). It also important to note that A5 and A6 components are pointing inwards so that the end assemblies sit at

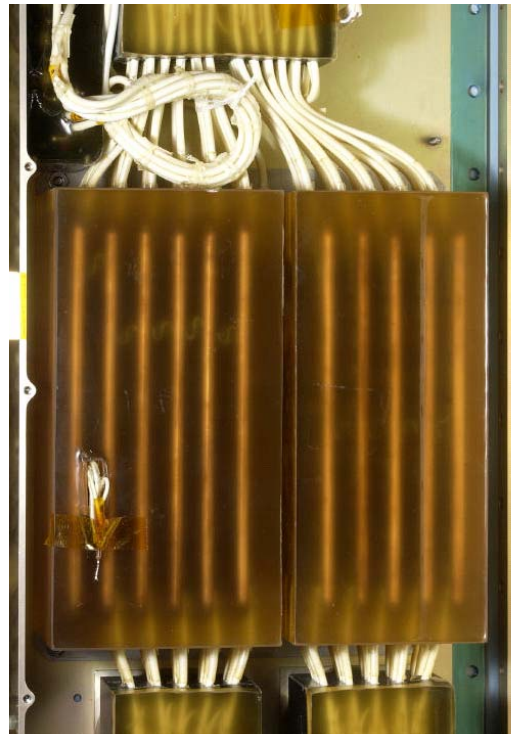

Figure 5: Flight Configuration of FEM

-20 kV or -16.3 kV, except A5's outside card always remains -16.35 kV (Focus electrode -45 plus Cathode potential). In addition the edges are rounded as it can be seen in figure 5 and 6, to minimize edge effects. Figure 6, shows the voltage

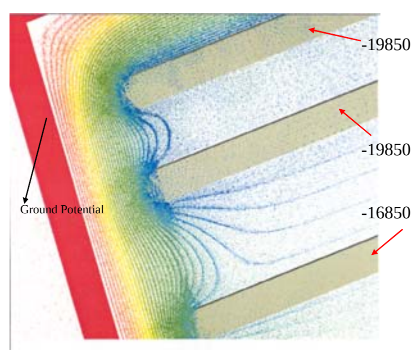

Figure 6: Voltage distribution across FEM

distribution, Individual Assemblies and final assembly is corona free at operating voltages.
Further, it was important to maintain reasonable temperature rise and profile .and the results are shown in figure 7.

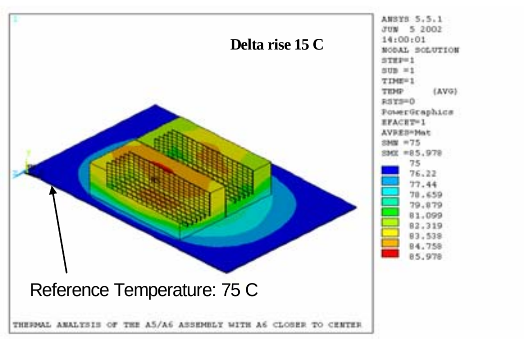

Figure 7: Temperature rise profile

Test Data.

Testing to date including a large number of deliberate and accidental shorts at ambient pressure and vacuum, with and without the EIK (Extended Interaction Klystron). The FEM did not experience failure and the performance remained within requirements as shown in Table 2 and figure 9.

Table 2: Flight HPA 101, FEM data

Temperature HVPS/EIK Deg C	RF Delay nana sec	RF Rise Nano sec.	RF Storage Microsec	RF Fall time Nano Sec.
33/50	928.0	62.0	1.050	18.0
25/35	980.0	57.0	1.080	22.0
0/20	922.0	50.0	1.020	28.0
-20/-15	910.0	49.0	0.950	14.0
-15/5	902.0	52.0	1.004	14.4
10/15	920.0	54.5	1.039	22.0
25/25	948.0	59.0	1.084	25.0
23/23	888.0	52.0	1.000	22.6

Conclusion.

It is clear that EIK's requirement of 200

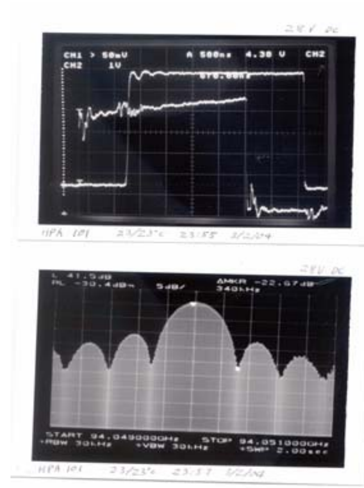

Figure 9: FEM Command, RF output and Spectrum in TV

nanoseconds for rise time and fall times has been met over the specified environment. And Data collected is within the CPR requirement and performance is very satisfactory.
When launched, it will be the first such instrument in orbit to deliver 2 kW of RF power in with such a fast FEM.
In author's opinion this approach to the design, is adaptable to any range of voltage swings (excursions) if attention is paid to the pulse transformer design, selection of FETs.

References

[1] Brian Steer et al., "The CloudSat Extended Interaction Klystron", 2nd IEEE International Vacuum Electronics Conference 2001, Noordwijk, The Netherlands, 2-4 April 2001
[2] Dave Berry, Albert Roitman and Brian Steer, "State-of-the-Art W-band Extended Interaction Klystron for the CloudSat Program" 5th IEEE

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